EVALUATION OF POLYMER SOLIDS SEPARATION, NITRIFICATION-DENITRIFICATION AND SOLUBLE PHOSPHORUS REMOVAL SYSTEM FOR TREATING SWINE MANURE

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ABSTRACT

Manure nutrients in excess of the assimilative capacity of land available on farms, ammonia emissions, and pathogens are often environmental concerns with confined livestock production. We evaluated an alternative system for treatment of liquid swine manure where the lagoon is omitted. In this multistage system, solids and liquid are first separated with polyacrylamide (PAM) polymer, followed by biological N removal using nitrification and denitrification and then P extraction through a lime precipitation process. The pilot system was evaluated for 1 yr at the Swine Unit at NCSU Lake Wheeler Rd. Field Laboratory using flushed swine manure from finishing and breeding houses. The average TKN concentration in the flushes was 555 mg/L with 64% in organic N forms and 36% as ammonia N. The total P averaged 245 mg/L with 88% organic P and 12% phosphate. Other characteristics of the liquid manure were: total suspended solids = 5900 mg/L; volatile suspended solids = 4800 mg/L; and BOD = 2600 mg/L. For solids separation, we used an in-line PAM injector and mixer to flocculate the solids in the flush and a sand filter bed for dewatering. PAM treatment reduced 85% of BOD, 98% of TSS and VSS, 60% of TKN, and 75% of TP. This treatment removed most of the organic nutrients from the liquid (89% of org. N and 93% of org. P) but not soluble N or P fractions. For N removal we used nitrifying bacteria entrapped in polymer pellets in aerated tank and denitrifying sludge in anoxic tanks that removed > 90% of the ammonia N in the liquid after solids separation. Soluble P was effectively recovered as calcium phosphate (17% P_2O_5) after removal of ammonia and carbonate buffers during nitrification and precipitation with $Ca(OH)_2$. Pathogens (i.e., salmonellae, enterococci) were reduced at least 4 logs. Overall, our results indicate that systems without lagoons are technically feasible. A full-scale system will be demonstrated under the Smithfield Foods/PSF & NC Attorney General Agreement for verification of Environmental Superior Technology.

SYSTEM CONCEPT

The usefulness of polymers to flocculate and increase separation of solids from liquid swine manure has been demonstrated (Vanotti and Hunt, 1999). Along with the solids there is a significant capture of organic nutrients associated with the clumping of the small particles that usually escape screens or clog sand filters. Soluble ammonia and phosphorus levels, which may constitute 35-45% of total N and 15-25% of total P, are mostly unaffected by polymer separation and need further treatment when land application is not an option. While biological nitrogen removal is regarded as one of the most effective methods to remove ammonia, its application to animal wastewaters is a challenge because ammonia in high concentration (250-2500 mg/L) can be toxic to the nitrifying microorganisms. Using acclimation and immobilization techniques, we have shown that biological nitrification can be an effective option to remove nitrogen both from hog lagoons and landfill-leachate effluents with a high ammonia concentration (Vanotti et al., 2000, Ellison et al., 2001). Solids separation with PAM reduces up to 98% of the suspended solids and removes most of the volatile and oxygen demanding compounds from the liquid stream. Instead of breaking down organic compounds, the oxygen in the aeration treatment following solids separation can be used efficiently to convert ammonia in the nitrification process. A logical question that follows is if the nitrification process can be coupled with the effluent after polymer separation to treat fresh liquid manure. This study was conducted to evaluate whether this sequence is technically feasible. Further, we evaluated phosphorus extraction technology to remove soluble phosphate for application to situations where soil P levels in sprayfields are high and its disposal is a problem. This multistage system can be precursor of new total systems alternative to the lagoon-sprayfield technology. Such a system was pilot tested at the Swine Unit at NCSU Lake Wheeler Rd. Field Laboratory. A full-scale system based on these studies was approved for full-scale demonstration and performance verification under the Smithfield Agreement program.

ENHANCED SOLIDS-LIQUID SEPARATION COMPONENT

For solids separation, we used a Deskins[1] in-line PAM injector and mixer to flocculate the solids in the flush and two sand filter beds (20 x 16 ft) for dewatering. The beds were constructed with several layers of media starting with a 45-cm layer of washed stone (1.9-cm size), then a 15-cm middle layer of pea gravel (0.95-cm size) and PVC media for stabilization, and topped with 15 cm of coarse sand (0.5-mm size). Flushed manure was first mixed in a homogenization tank and pumped at 130 gal/min to the polymer injection unit (used Magnifloc c-1596 polymer, Cytec Industries, Inc.) before application to the sand filter bed. The beds received 30-cm depth of flocculated liquid during each pour. Solids content in the flush was initially low (<1 g/L). After run 6, the flushes were held for one or two days to increase accumulation of manure in the houses and obtain a range of solids concentration more representative of flushes in commercial operations (Figure 1). Separation efficiencies of 98% for TSS, 85% BOD, 75% TP and 60% TKN were obtained on the average (Table 1). Organic N and P were efficiently separated but not the NH_3 and phosphate fractions.

FIGURE 1: Solids Separation with PAM

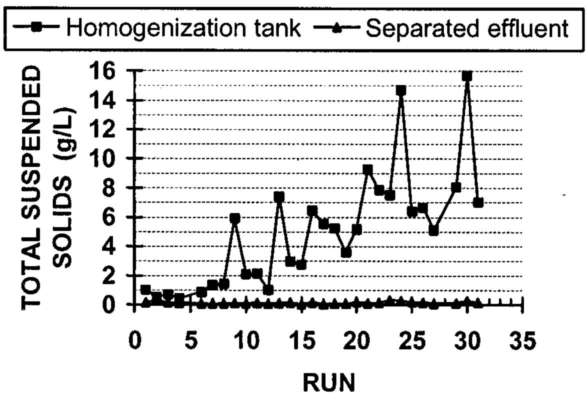

Table 1: Enhanced Solids and Nutrient Separation From Flushed Swine Manure Using Polyacrylamide (PAM) Polymer Flocculation and Separation With Sand Filter Bed [a]

Flush Constituent	Homogenization tank (mg/L)	PAM Treated Effluent (mg/L)	Separation Efficiency (%)
Total Suspended Solids	5846	141	98
Volatile Suspended Solids	4775	118	98
BOD 5-days	2576	387	85
Total Kjeldahl Nitrogen	555	224	60
Total Phosphorus	245	62	75
Organic Nitrogen	353	40	89
Organic Phosphorus	215	14	93

[a] Data is average of 27 trials during a 1-year period. Range of initial concentrations varied: TSS = 1.3 to 15.7 g/L, VSS = 1.1 to 13.5 g/L, BOD = 0.6 to 8.5 g/L, TKN=300 to 1140 mg/L, TP = 90 to 620 mg/L.

BIOLOGICAL NITROGEN REMOVAL COMPONENT

[1] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agriculture and does not imply its approval to the exclusion of other products or vendors that also may be suitable.

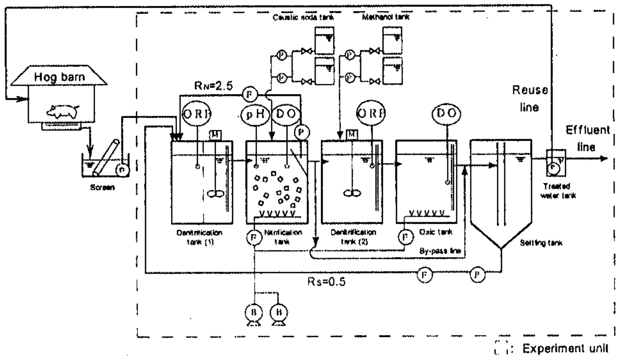

Figure 2: System for Biological N Removal

A system that uses nitrifying pellets in an aerated tank and denitrifying sludge in anoxic tanks was used to treat the effluent after solids separation with PAM (Figure 2). The pilot unit was designed to treat 1 m^3/day of liquid at 10°C water temperature. It contained a 1.3 m^3 anoxic denitrification tank (1) with ~ 3 g/L MLVSS to remove soluble carbon and NO_3-N, a 0.55 m^3 nitrification tank containing 100 L of polyethylene glycol (PEG) pellets for conversion of NH_4^+ to NO_3^-, a 0.63 m^3 clarification tank for settling of suspended solids, pH and ORP controllers, and monitoring and sampling equipment. The unit also included a second 0.63 m^3 tank (2) with methanol injection for post-denitrification when needed and a small 20 L oxic tank to enhance settleability. The nitrifying pellets were provided by the Hitachi Plant Construction & Engineering Co. of Japan. The pellets were first acclimated to swine wastewater during a 60-day period where nitrification activity increased from 0 to an optimum of 790 g N/100-L pellets/day. Nitrified water was recirculated (R_N) to the denitrification tank (1) at a rate of 2.5 to 7.5 m^3/day and settled sludge was recycled (R_S) at 0.5 to 1.5 m^3/day. This pre-denitrification configuration has the advantage that it uses naturally available carbon source from manure for denitrification and reduces organic loads to the nitrification tank. When coupled with denitrification, the natural alkalinity in wastewater (1200-1800 mg/L) was sufficient for a complete nitrification without needs for alkali supplements. We found that a COD/N ratio > 5 optimized the denitrification process and that sufficient soluble C was available in the system when the manure flush contained > 0.5% suspended solids (Figure 1). A nitrified liquid recycle rate (R_N) of 5/1 optimized conditions.

Table 2: Carbon and Nitrogen Removal Using Nitrification /Denitrification After Solids Separation [a]

	Post-polymer	Post-N Removal	% Efficiency
pH	7.7	7.9	--
COD	1497	220	85
Total N	259	25	90
NH_3-N	231	1	99

a COD and N values are concentration in mg/L.

PHOSPHORUS EXTRACTION COMPONENT

Once ammonia and carbonate alkalinity concentrations are substantially reduced with a nitrification pre-treatment, the subsequent addition of $Ca(OH)_2$ rapidly increases the pH of the liquid above 9, thereby promoting formation of calcium phosphate precipitate with small amounts of chemical added (Vanotti et al., 2001). Hydrated lime (2% $Ca(OH)_2$) was added and mixed with the effluent after biological N removal in a stirred tank and subsequently settled in a conic tank where the precipitate was removed from the bottom of the tank. The hydrated lime was added to reach a set point pH of 10.5 in order to remove all soluble P and kill pathogens. An average of 280 mg/L of $Ca(OH)_2$ was needed to reach this point, corresponding to a 1.33 Ca/P molar ratio. Results shown in Table 3 indicate that the treatment was highly effective to recover soluble P from swine wastewater. Precipitate solids contained ~ 17% of P_2O_5.

Table 3: Phosphorus Precipitation With $Ca(OH)_2$ After Biological N Removal [a]

	Post-N Removal	Post-P Removal	% Efficiency
pH	7.5	10.4	--
Alkalinity	243	295	--
COD	236	126	47
Total P	88.4	8.5	90
PO_4-P	51.3	0.5	99

[a] Except pH, values are concentration in mg/L.

MICROBIOLOGICAL ANALYSES

Each step of the treatment system was evaluated for its effectiveness in reducing pathogens, by counting total and fecal coliforms, enterococci, and salmonellae on selective and differential nutrient media. Results (Table 4) show a consistent trend in reduction of salmonellae, total and fecal coliforms, and enterococci as a result of each step in the treatment. In general, the lowest concentrations of salmonellae and pathogen indicators occurred after nitrification/denitrification and phosphorus removal steps.

TABLE 4. Microbiological Analyses of Effluents at Each Step in the Treatment System [a]

Treatment Point	Total Coliforms	Fecal Coliforms	Enterococci	Confirmed Salmonellae [b]
Wash Water from Lagoon [c]	3.58±3.31	3.06±3.13	3.36±2.96	3.89±3.93
Homogenization Tank	6.60±6.35	4.65±3.95	5.43±5.07	4.37±4.45
Post- Polymer	6.63±6.66	5.16±4.61	4.12±3.90	4.15±4.24
Post- Nitrification/ Denitrification	1.0±0	≤0.95	1.18±0.85	2.88±2.98
Post-Phosphorus Removal	<0.30	<0.30	<0.30	<0.30

[a] Values are mean ± standard deviation of $\log_{10}$colony forming units per mL for duplicate samples for two trial runs of the system (except for post-denitrification which represents duplicates of the second trial only); < indicates colonies were too few to count, thus only the upper threshold limit value can be calculated.

[b] Presumptively positive salmonellae were confirmed by serological test.

[c] Lagoon liquid used to flush the houses; samples taken from the flush tank.

FULL-SCALE SYSTEM DEMONSTRATION

The multistage wastewater treatment system outlined in this paper integrated with a solids processing facility to make added-value products from the separated solids was one of the technologies selected through a competitive review process under the Agreement between Smithfield Foods, Inc./Premium Standard Farms and the Attorney General of North Carolina for full-scale demonstration and environmental performance verification including operational and economic feasibility. The project was awarded to Super Soil Systems USA of Clinton, NC. The treatment facility will treat 125 m^3/day of liquid swine manure at a 4,360-pig farm in North Carolina's Duplin County and replaces a lagoon/sprayfield system. A solids processing facility near Clinton, NC, will compost the solids from 16-32 farms and produce specialized mixtures for soil amendments, organic fertilizers, and plant growth media markets using Super Soil Systems' technology. The wastewater system separates the solids and liquids using polymer PAM technology and Ecopurin module of Selco M.C. (Spain), removes the nitrogen from wastewater with immobilized pellet technology using Biogreen module of Hitachi Plant Engineering & Construction Co. (Japan), extracts the phosphorus using USDA-ARS technology, and recycles clean water for the flushing of the swine houses.

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